A Millimetre Wave Phase Shifter Using A Wireless Hybrid Mode Locked Laser

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Abstract: 40GHz hybrid mode locking is observed using planar antennas to form a wireless connection to the saturable absorber. Electronically controlled phase shift is measured which could enable remote antenna beam steering in future WLAN systems.

OCIS codes: (060.5625) Radio frequency photonics; (140.4050) Mode-locked lasers;

1. Introduction

There is much interest in the use of the millimetre wave (mm-wave) radio bands for next generation WLANs operating at > 1Gbps [1-3]. There are, for example, recently released standards for consumer based systems for distribution of High Definition TV signals around the home operating at 4Gbps with a 60GHz carrier [4]. It has long been recognized that Radio-over-Fibre (RoF) could play an important role in systems such as this when signals need to be distributed over many 100's or 1000's of meters [5]. Cost will be a very important factor in the success of these systems and the main issue for RoF solutions is the cost of modulating a laser at 60GHz. Traditionally this would be done with an expensive Electro-Optic modulator [3] although more recently Electro-Absorption modulators have been explored [6]. One interesting, potentially low cost, solution is the use of Mode Locked Lasers (MLLs) that can be designed to operate at millimetre pulse repetition frequencies [7]. Not only can these devices be used to transmit data on a mm-wave carrier, they can also implement mm-wave phase shifting [8] which can be used for smart antenna beamforming. To achieve this, at low cost, antennas and lasers will need to be integrated together and some progress has been made on this front at low frequencies [9]. This paper presents what is believed to be the first example of a hybrid MLL driven by a planar antenna connected to the saturable absorber (SA) section. The paper shows that phase shifts of 70^o degrees can be achieved, albeit at short ranges and over narrow bandwidths. These results are a first step in the direction of full monolithic integration of MLLs and antennas which could form an important part of low cost, mm-wave based WLAN systems.

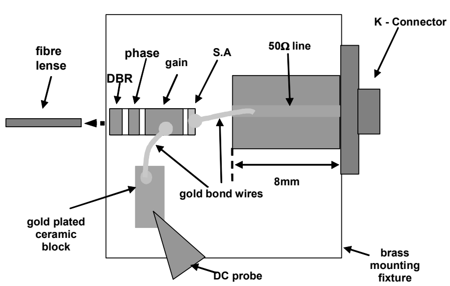

Figure 1 : Schematic of mounting configuration for MLL testing

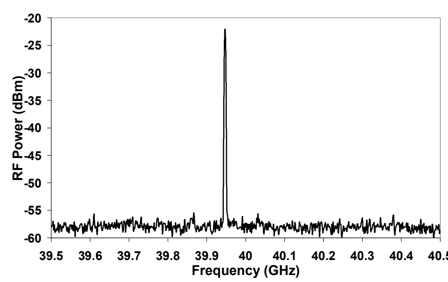

Figure 2: Measured millimetrewave spectrum of passive mode locking at V_{sa} =-1.0V

2. Results

2.1 40GHz Mode-Locked Laser (MLL)

The MLLs used for measurements have been supplied by HHI, Berlin [10]. They are multi-section devices comprising SA, gain and phase sections along with a DBR for wavelength tuning. The total length of the device 1080μm which produces an output pulse repetition frequency of around 40GHz. Figure 1 shows the device mounting configuration. The MLL was mounted on brass fixture and the gain section was connected using a bond wire to a separate gold plated ceramic block which was then probed to apply the forward bias to the gain section. A K-connector, 50Ω transmission line and gold wire bond are used to apply both RF power and reverse bias to the S.A section for hybrid mode-locking. The MLLs used have excellent output power characteristics giving more than 3.5mW of optical power into a fibre lens at 15^oC and 50mA gain section current. Initially passive mode locking results are presented. The mm-wave spectrum is observed using a high speed U^2T Photonics 50GHz photodetector and an Agilent 50GHz spectrum analyzer. The result is shown in figure 2 and a well defined mode locking spectrum

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is observed. The free running frequency of the MLL can be controlled by the SA voltage and gain section bias and has a range of 446.7MHz from 39.68- 40.13GHz for a range of SA voltages from -1.5 to -0.5V and gain section bias currents of 90mA – 150mA respectively as shown in figure 3 below.

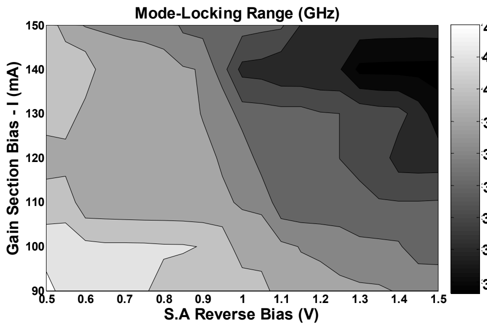

Figure 3 : Tuning range for passive mode locking at V_{sa} =-0.5V to -1.5V

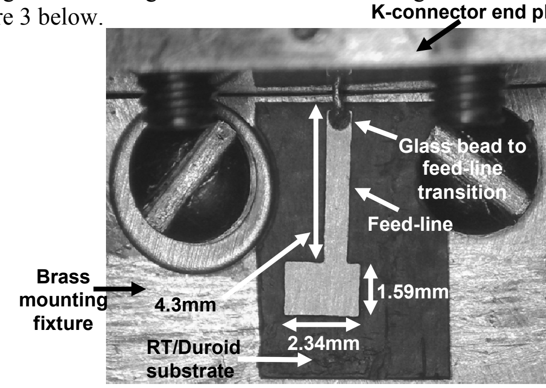

Figure 4 : 40GHz patch antenna mounting using a K-Connector

2.2 Millimetre-wave Patch Antenna Design

The patch antennas are designed using the Agilent Advanced Design System Momentum simulator. Standard rectangular patch antennas have been used in this case and they are designed to operate around 40GHz. RT/Duroid high frequency glass microfibre substrate ($\varepsilon_{r=}$ 2.33 and thickness = 0.254mm) is chosen for antenna design because of its low loss and good working characteristics at mm-wave frequencies. The antennas were mounted on brass fixtures shown in figure 4 and have dimensions of 1.59mm x 2.34mm. Figure 5 shows the measured and modelled return loss for two antennas and good agreement is observed. The antennas have a bandwidth of >1GHz which would support multi-gigabit bandwidth communications.

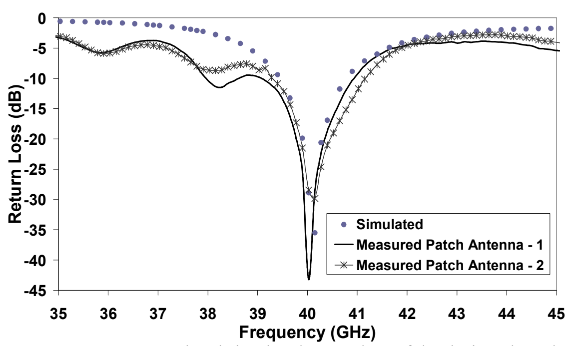

Figure 5 : Measured and simulated return loss of the designed patch antennas

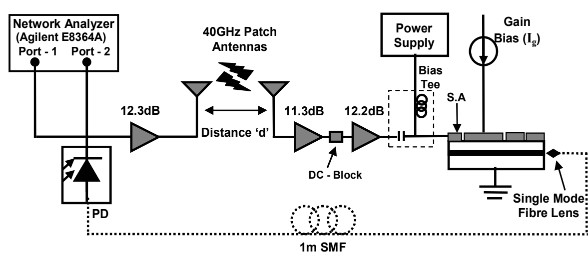

Figure 6: MLL measurement setup using modular Integration of mm-wave patch antenna and amplifiers for phase shift measurements

2.3. MLL and Patch Antenna Measurement Results

The patch antenna is then connected to the SA section of the MLL using a high frequency V coaxial cable and the set up is shown schematically in figure 6. A novel measurement configuration is then used to observe hybrid mode locking using the phase locked nature of a Vector Network Analyser (VNA). Port 1 of the VNA is connected to a 40GHz Hittite (HMC-ALH369) low noise +12.3dB amplifier (LNA) and then to the transmitting patch antenna. The radiated signal is received at the second antenna and fed through two mm-wave LNAs connected in series having gains of +11.3dB and +12.2dB respectively and finally connected to the SA section via coaxial cable. The optical output of the MLL is then fed through a single mode fibre to the photodetector and back into port 2 of VNA. The VNA measures the link gain (S_{21}) of the system, however, across the locking range of the hybrid MLL greatly enhanced link gain is observed due to the fact that the signals at port 1 and 2 will be phase locked as is required in a VNA. Thus, the locking range can be observed as a flat “plateau” in the S_{21} amplitude response shown in figure 7. The VNA also allows direct measurement of the phase of S_{21} and this allows observation of phase shifter operation. This phase shift occurs due the fact that under injection locked conditions the mm-wave frequency of the MLL is controlled by the external locking signal. Thus, if an attempt is made to change the MLL frequency by changing the SA bias for example, the MLL frequency cannot change and thus the only option available for the system is a change in phase. Figure 8 shows that phase shifts of up to 70degrees can be obtained. This would mean that two or more of these antenna-MLL systems could be used to create steerable beams usable within a WLAN system.

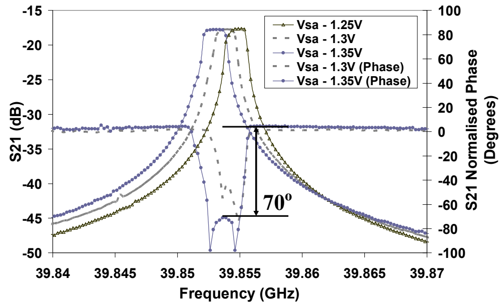

Figure 7 : Measured magnitude and phase of S21 at different SA reverse bias values (Phases are normalized to Vsa=-1.25V)

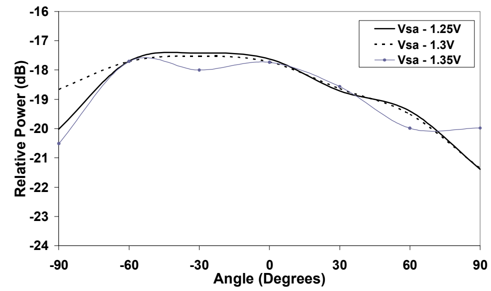

Figure 8 : Measured radiation pattern at V_{sa} =-1.25V to -1.35V

A very short wireless range of 10cm between antennas is used in this case and this corresponds to a path loss of -32.5dB using the Friis formula [3]. It is hoped to improve this range in future work by performing impedance matching at the SA section and using higher gain amplifiers. It is also possible to use electroabsorption (EA) based MLLs which have been shown to have very wide locking ranges [10]. The amount of injected RF power is an important parameter since with greater input power producing increased locking ranges and hence wider "plateau". In this case the power input to the SA section is estimated to be -10.4dBm. This is much lower RF injected power than is typically used for these devices which was >10dBm in [10] and accounts for the quite narrow locking ranges observed here. It is also important to observe the radiation patterns and this can be measured directly by rotating the angle of the receiving antenna. Figure 8 shows the results at different V_{sa} values of -1.25V to -1.35V. It can be seen that very consistent patterns are being obtained at the different V_{sa} values implying that good beamforming operation will be possible.

3. Conclusion

This paper has shown what is believed to be the first example of hybrid mode locking using a wireless connection to the SA section. The paper has also shown a novel phase shift characterisation scheme using the phase locked nature of a VNA. Phase shifting is observed across the locking range of the system and this will enable arrays of such devices to perform beam steering, which is seen as a key element of mm-wave WLANs. This paper has shown a modular integration approach using K-connector fixtures, future work will combine the MLL, amplifiers and planar antenna on the same mount to create a very compact module. This is a stepping stone to full monolithic integration of MLLs with antennas which could dramatically reduce the costs of such radio-over-fibre systems. There is an issue with the integration of amplifiers in this case, but there are a number of novel schemes that have been suggested to achieve this for example [11].

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